COMPUTER-AIDED SYSTEMS ENGINEERING

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Dr. S. Andriole

SPC-94039-CMC

Version 01.00.00

JUNE 1994

This material is based in part upon work sponsored by the Advanced Research Projects Agency under Grant # MDA972-92-J-1018. The content does not necessarily reflect the position or the policy of the U.S. Government, and no official endorsement should be inferred.

This document accompanies a videotape of the same presentation recorded live at the Software Productivity Consortium in March 1994. It is recommended that the videotape be viewed with these viewgraphs at hand.

Produced by the
SOFTWARE PRODUCTIVITY CONSORTIUM
under contract to the
VIRGINIA CENTER OF EXCELLENCE
FOR SOFTWARE REUSE AND TECHNOLOGY TRANSFER
SPC Building
2214 Rock Hill Road
Herndon, Virginia 22070

ABSTRACT

Computer-Aided Systems Engineering

Dr. Stephen J. Andriole
Drexel University

This presentation includes information concerning toolset requirements, current and projected tools, tool capabilities assessment and perceived critical deficiencies. Dr. Andriole presents a tools assessment matrix that demonstrates a mapping between toolset requirements and currently available systems engineering tools. He discusses the benefits and problems that organizations experience with tools. The timing and costs of investments in tools, how tools can be expected to perform and future expectations are presented.

Dr. Andriole explains why companies choose tools, identifies the most favorable environments and discusses common obstacles to successful CASE use. This video is intended for systems and software engineering development lead engineers, project managers and division managers working in the area of system and software engineering. Viewers will benefit by gaining information about systems engineering tools and automation, especially the value and capability of commercial off-the-shelf (COTS) tools. Dr. Andriole emphasizes the use of lower cost PC based (DOS or MAC) tools to support systems engineering activities including requirements modeling, simulation and prototyping, evaluation and trade-off analysis, testing and reliability, technology forecasting and risk analysis.

Dr. Andriole presents an overall framework for evaluating systems engineering tools based on how effectively the tools support the systems engineering process, followed by an overview of selected tools that are currently available.

Dr. Andriole is the Director of Information Systems Technology Laboratory at Drexel University. Prior to this he worked for several years at the Defense Advanced Research Projects Agency and was a professor at George Mason University. Dr. Andriole has broad expertise in the area of systems analysis and systems engineering of software intensive systems. He has published several articles related to systems engineering tools.

Computer-Aided Systems Engineering

An Assessment of Current Practices, Tools & Trends

Stephen J. Andriole

The Assessment Framework

- **Systems Engineering**
- **The State-of-the-Practice of Computer-Aided Systems Engineering**
- **The Generic Systems Engineering Framework**
- **Phase-by-Phase Organization & Categorization**
- **Criteria-Based Evaluation & Assessment ---> The Matrix**
- **COTS/CASE Tools Sampler**
- **SPC COTS/CASE "Products" & Services ...**

The State-of-the-Practice of Computer-Aided Systems Engineering

- "Practiced" for Years by Systems Engineers
- Opportunistic -- Not Characterized by the Same Zeal or Investments that Characterize the Computer-Aided *Software* Engineering Movement
- In Many Respects -- Further Integrated into the Other-Than-Software-Intensive Design & Development Process Than in the Software-Intensive Systems Design & Development

The State-of-the-Practice of Computer-Aided Systems Engineering (Continued)

- **Practiced as Pieces of a Greater Whole:**
  - **Cost-Benefit Modeling**
  - **Technology Forecasting**
  - **Project Management**
  - **Resource Allocation**
  - **Cost Estimation**
  - **Trade-Off Analysis ...**
  - **No "I-CASE" ... Yet ...**
- **"Attached" to Life Cycle Phases**

The "Generic" Systems Engineering Framework

- **May Be Described -- Like the Software (Systems) Engineering Life Cycle -- as a "Conversion Process" -- From Fuzzy & Ill-Understood Requirements to Detailed Design & Measurable Performance**
- **Well-Supported by "Standards", Such as Blanchard's Framework & 499A/B**
- **Characterized by:**
  - **Objectives (by Phase & Overall)**
  - **Methods**
  - ***Tools***

Systems Engineering

- The Process by Which we Convert Complex Requirements into Working, Maintainable Systems is Part of the Discipline and Structure Known as ***Systems Engineering***

- While there are All Sorts of Variations on this Theme, Systems Engineering Refers to Those Processes and Activities that Together Define a Life Cycle that Follows a System Through Crude Concept Development, Testing and Evaluation, and Eventual Retirement

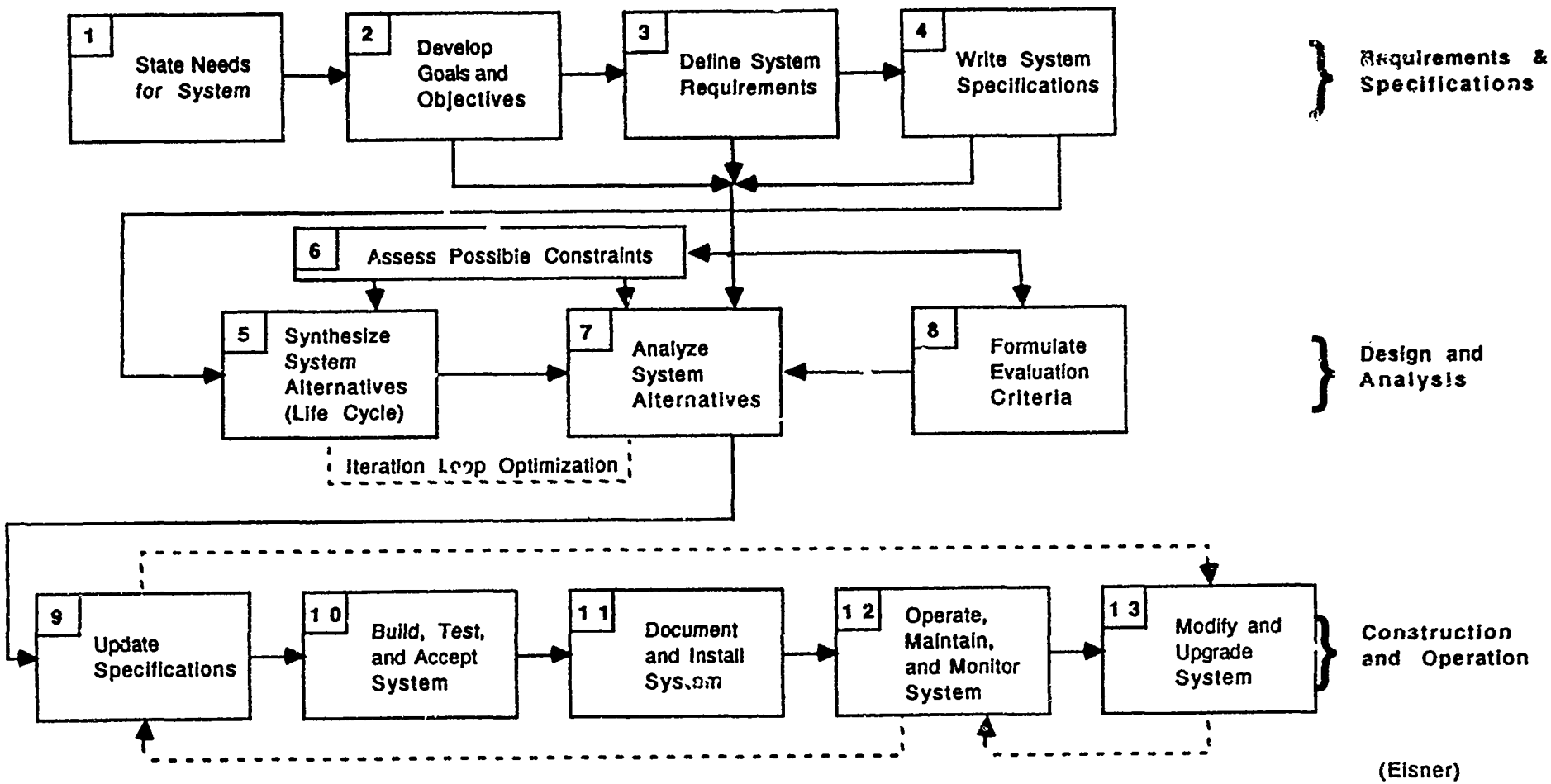
Systems Engineering

- Systems Engineering Traces its Origins to the Work of Hall (1962), Chestnut (1965; 1967), Chase (1974), Sage (1977; 1983), and Blanchard and Fabrycky (1981; 1990)
- More Recently, Sage (1992), Blanchard (1991), Eisner (1988), and Chapman, Bayhill and Wymore (1992) have Refined the Methods, Tools Techniques, Activities, Functions and Purpose of Systems Engineering
- Along the Way an Overarching Department of Defense Standard Evolved

Systems Engineering

- The Essence of the Systems Engineering Process is Requirements ---> Design ---> Development Efficiency
- The Primacy of Requirements is Well Documented (Andriole, 1989, 1990; Sage, 1992; Sage & Palmer, 1990; Davis, 1990, 1992)

Generic Systems Engineering Process



(Eisner)

Systems Engineering

- Eisner defines systems engineering as *"an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system."* Eisner describes the systems engineering process as consisting of 25 "elements"

Systems Engineering

1. Requirements Analysis
2. Requirements Allocation
3. Functional Analysis
4. Functional Allocation
5. Specification Analysis
6. Specification Development
7. Preliminary Design
8. Interface Definition
9. Schedule Development
10. Preliminary Cost-Analysis
11. Technical Performance Measurement
12. Trade-Off/Alternative Analysis
13. Pre-Planned Product Improvement
14. Final Design
15. Schedule Update
16. Cost Update

Systems Engineering

17. Fabrication
18. Coding
19. Preliminary Testing
20. Debugging & Reconfiguration
21. Testing & Integration
22. Updates

    A. Schedule
    B. Cost
    C. Technical Performance Measurement

23. Documentation
24. Training
25. Production

Systems Engineering

- 499A
- *"Systems engineering is the ... logical sequence of activities and decisions transforming an operational need into a description of system performance parameters and a preferred system configuration ... systems engineering is the application of scientific and engineering efforts to (a) transform operational need into a description of system performance parameters and a system configuration through the use of an iterating process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; (c) integrate reliability, maintainability, safety, survivability, human, and other such factors into the total engineering effort to meet cost, schedule, and technical performance objectives"*

Systems Engineering

- The Revised (Draft) Standard (DOD, 1992) -- 499B -- Describes the Systems Engineering Process as Follows:

  "A comprehensive, iterative problem solving process that is used to: (a) transform validated customer needs and requirements into a life-cycle balanced solution set of system product and process designs, (b) generate information for decision-makers, and (c) provide information for the next acquisition phase"

Systems Engineering Goals (After Sage)

- All (Life Cycle) Encompassing
- Problem Understanding
- Communication
- Early Capture of Design & Implementation Needs
- Bottom-Up & Top-Down Design & Development
- Alternative Systems Management Approaches
- Process & Product Quality Assurance
- Product Evolution
- Support for Configuration Management Standards
- Support for Automated Design & Development Aids
- Teachable & Transferable Methodology
- All phase Definition & Documentation
- Product Functionality, Revisability & Transitioning
- Support System Product Development & System User Organizations

Systems Engineering Management Plan (SEMP)

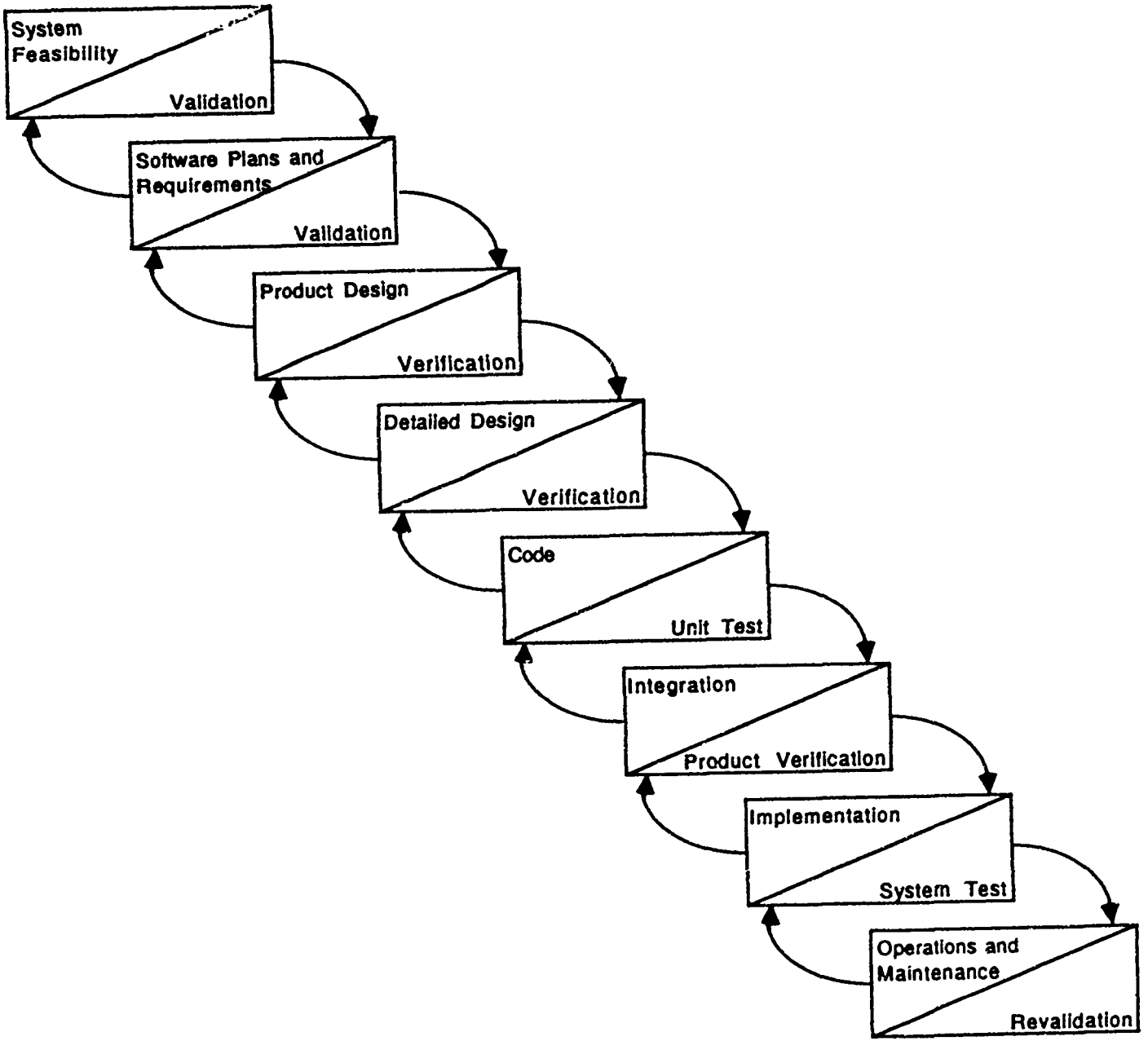
- At the Core of the Planning and Management Process lies the SEMP that Requires the Production of Documentation that can be Reviewed and Assessed. This Documentation Includes at Least the Following:

  - Project Management Schedules
  - Product Cost Estimation
  - Timeline Analysis Sheets
  - Requirements Allocation Sheets
  - Work Breakdown Structures
  - Technical Performance Measures
  - Human Factors Engineering Plan
  - Risk Management Plan
  - Data/knowledge Management Plan
  - Maintainability Plan
  - User Manuals

Systems Engineering Management Plan (Continued)

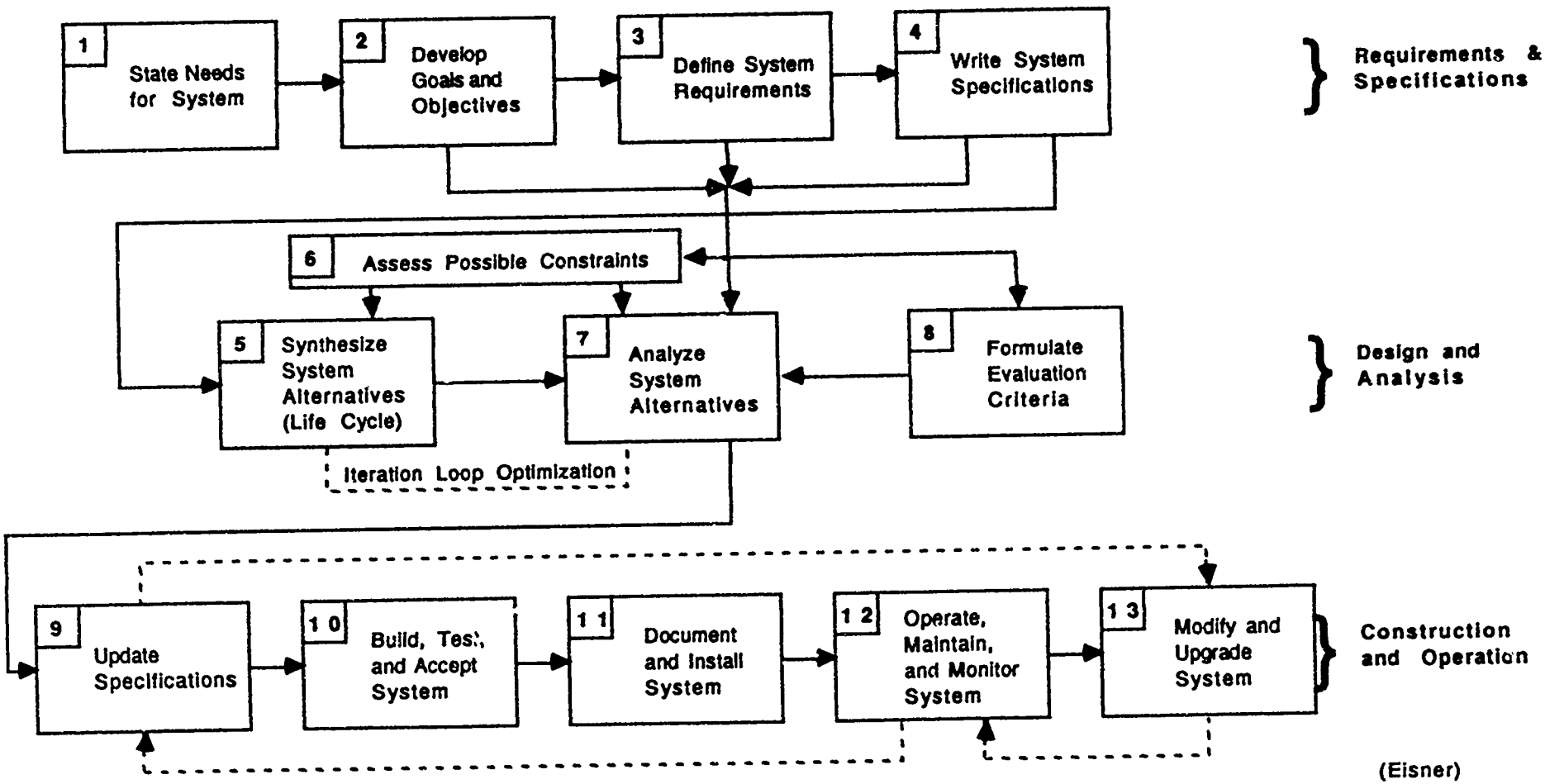
- Software Requirements Specifications (Preliminary & Detailed)
- Software Design Specifications
- Test & Evaluation Master Plan
- Configuration Management Plan
- Production/Manufacturing Plan
- Total Quality Management Plan . . .

The Waterfall Model Of The Software Life Cycle



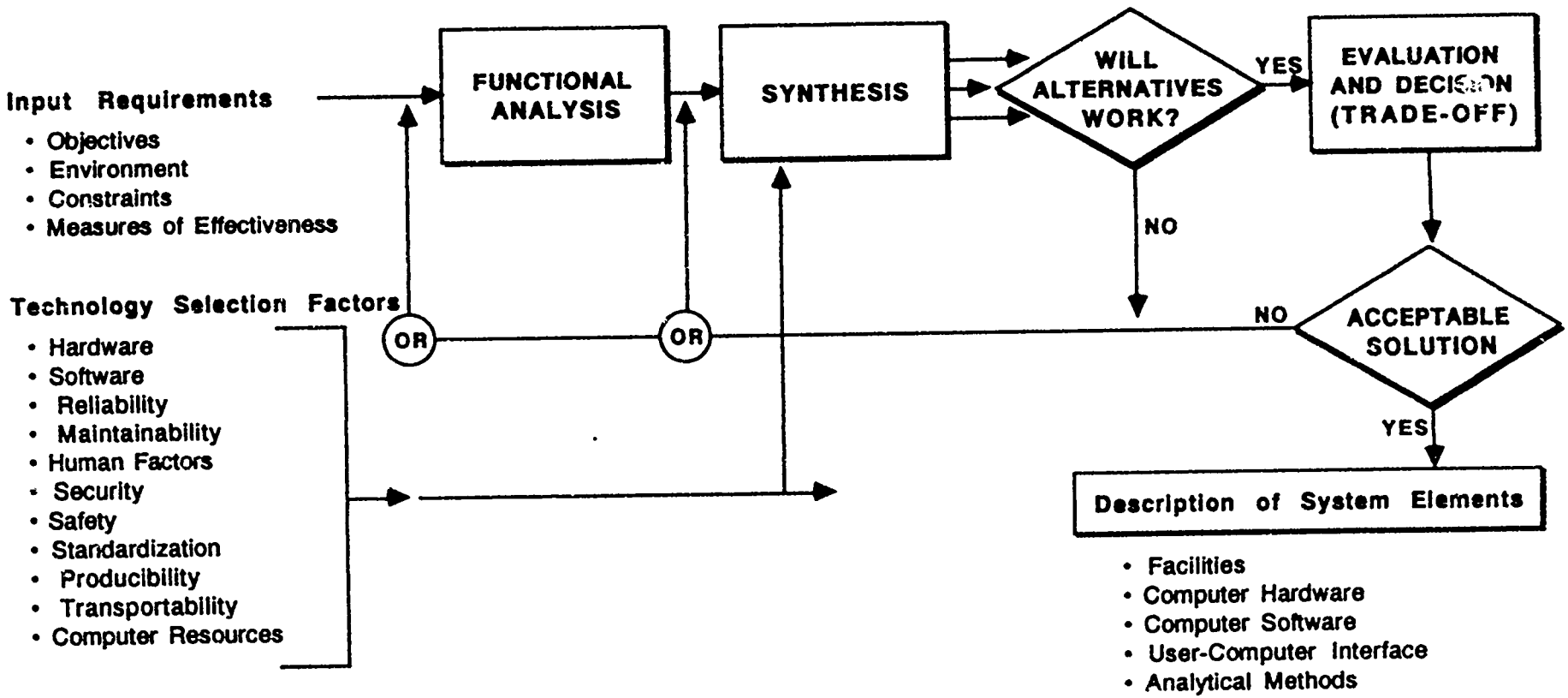
(Royce)

Generic Systems Engineering Process



(Eisner)

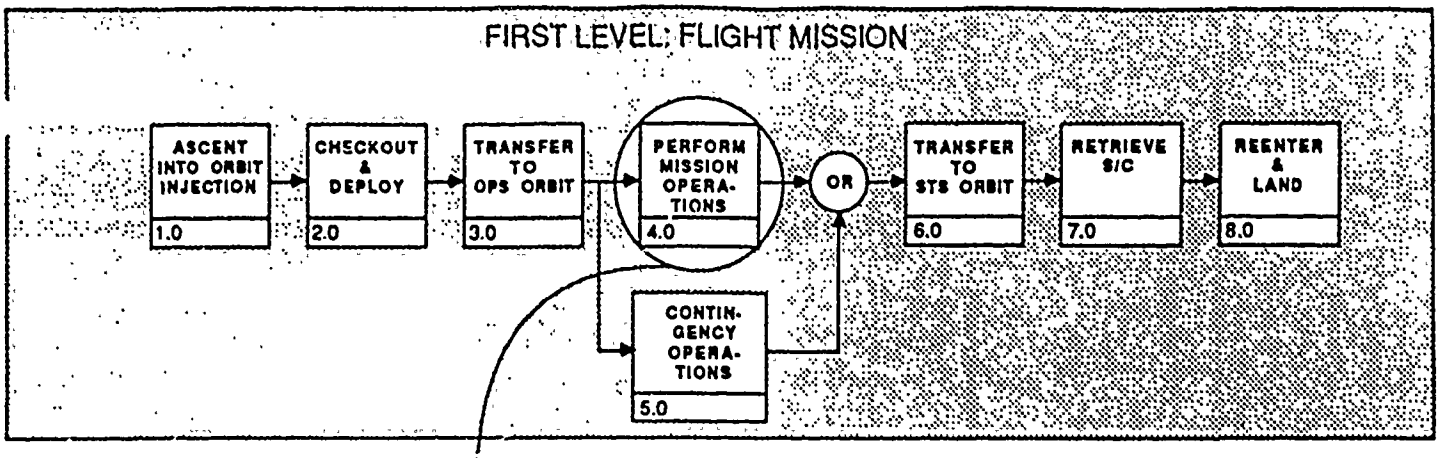
Generic Systems Engineering Process



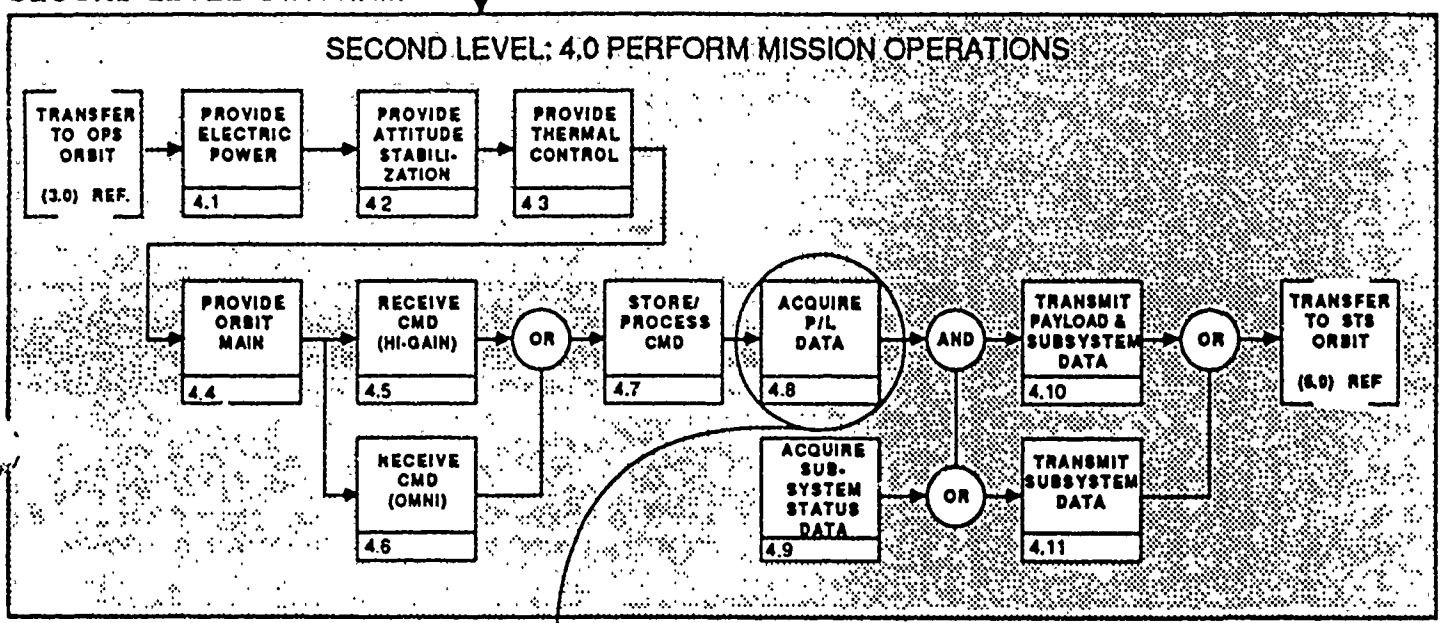
(Seng)

Development of Functional Flow Block Diagrams

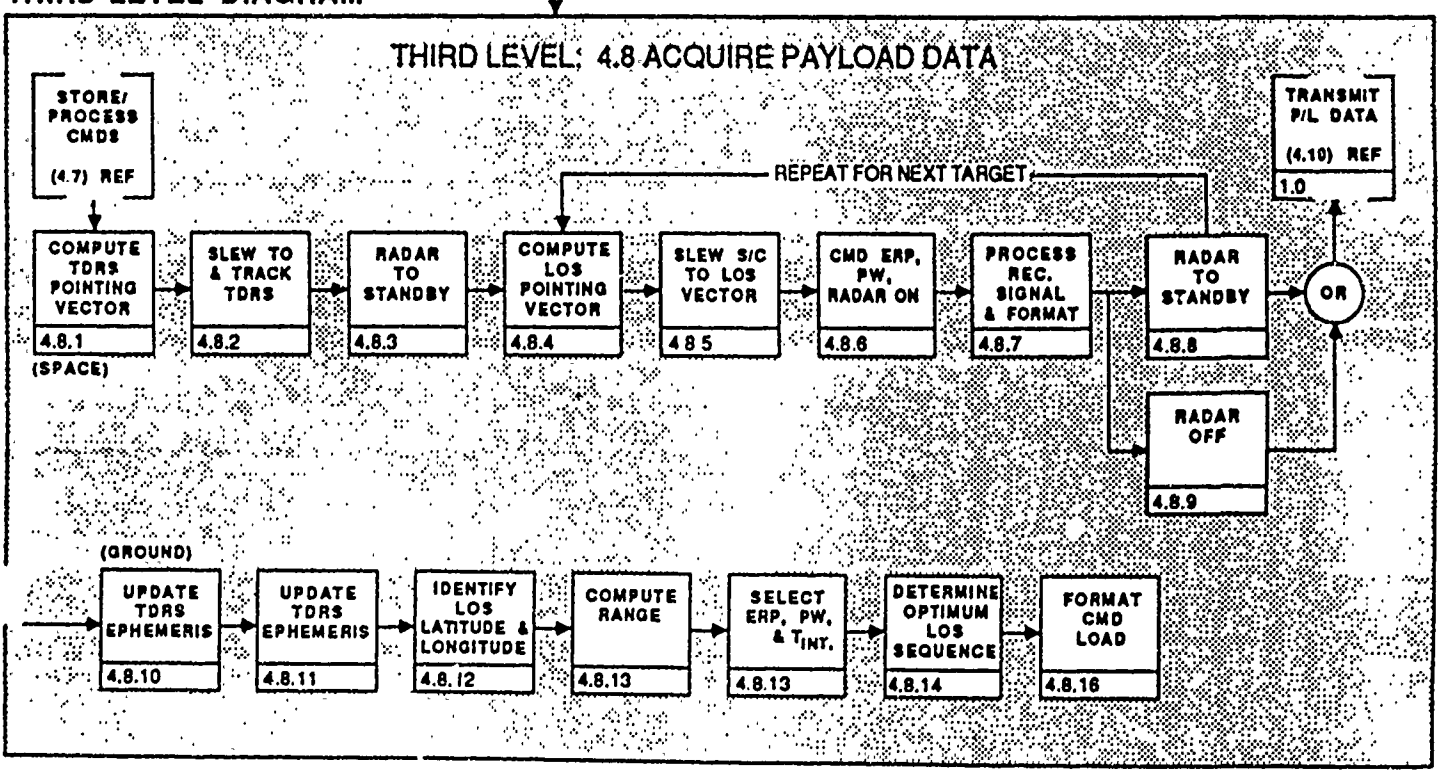
TOP-LEVEL DIAGRAM



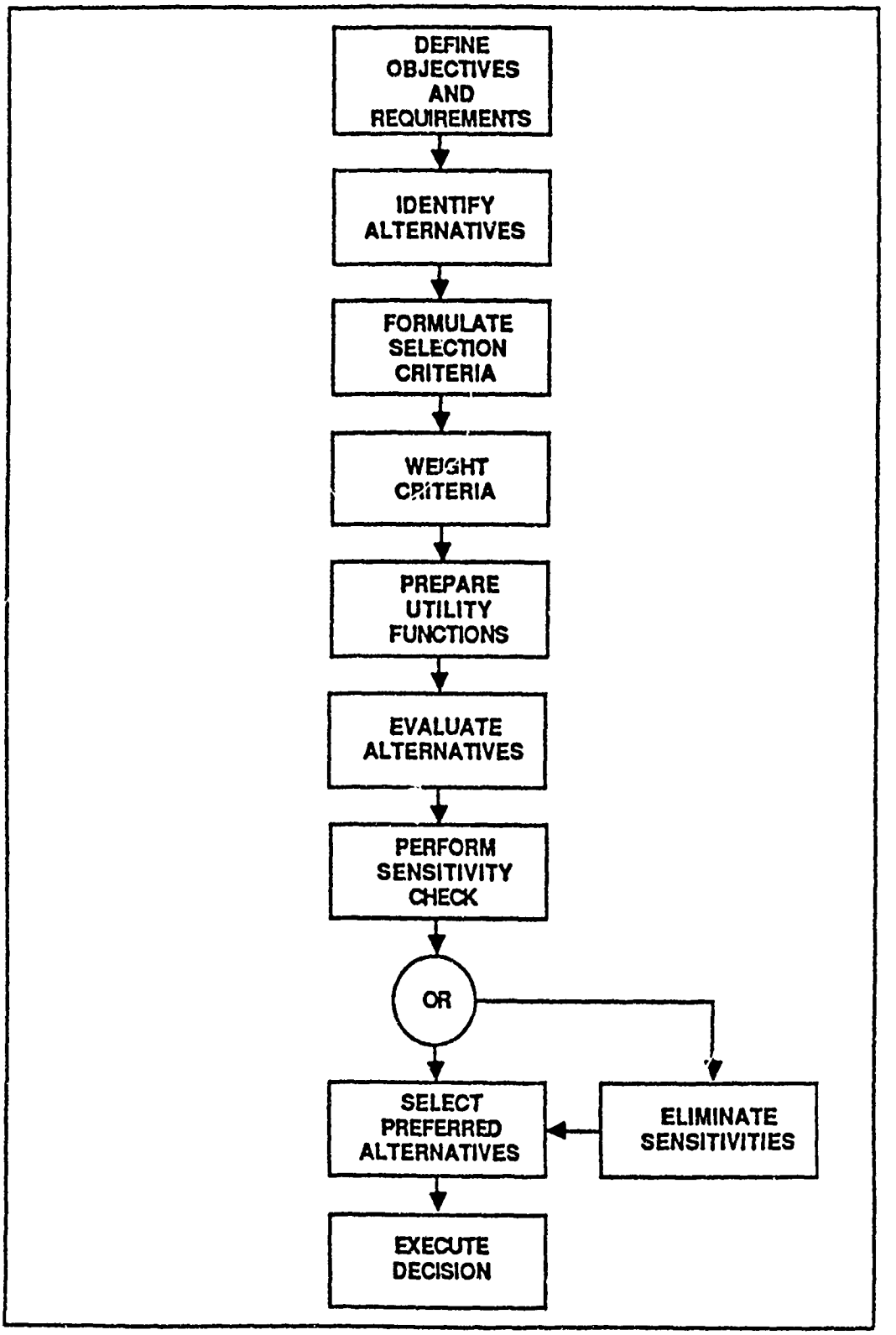
SECOND-LEVEL DIAGRAM



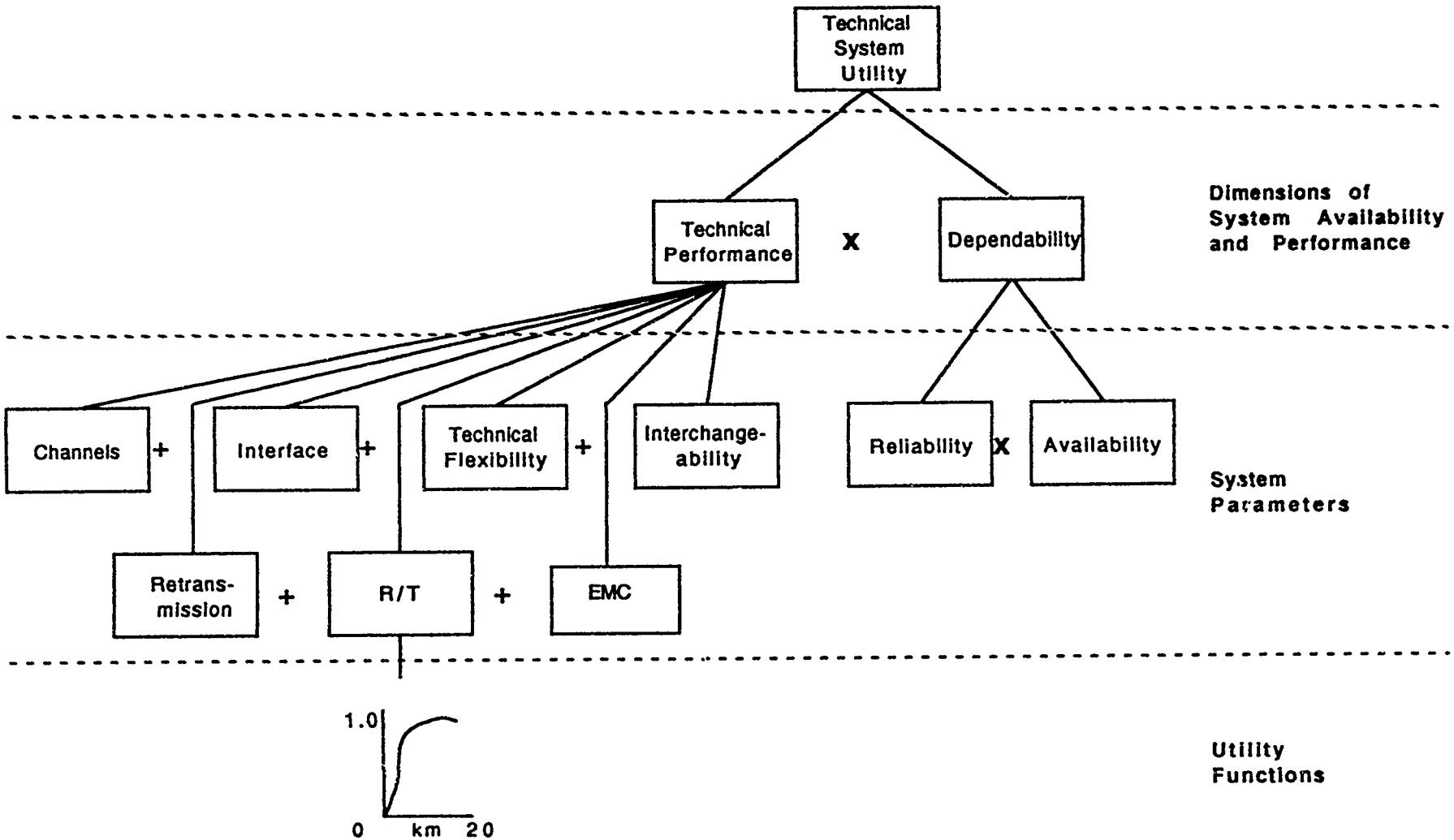
THIRD-LEVEL DIAGRAM



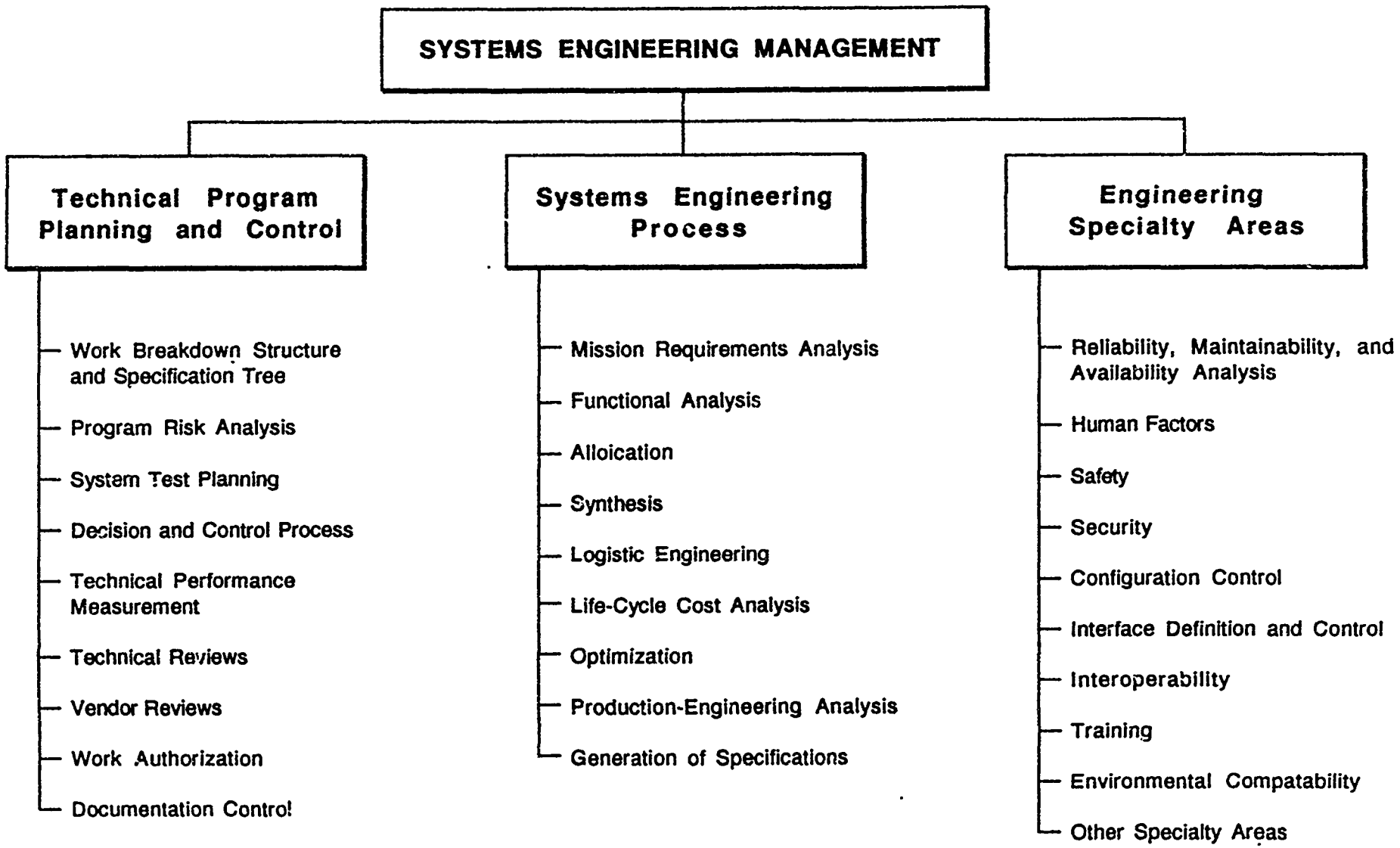
Trade-Off Analysis Methodology



A Simplified Structure Of A Radio Evaluation Model

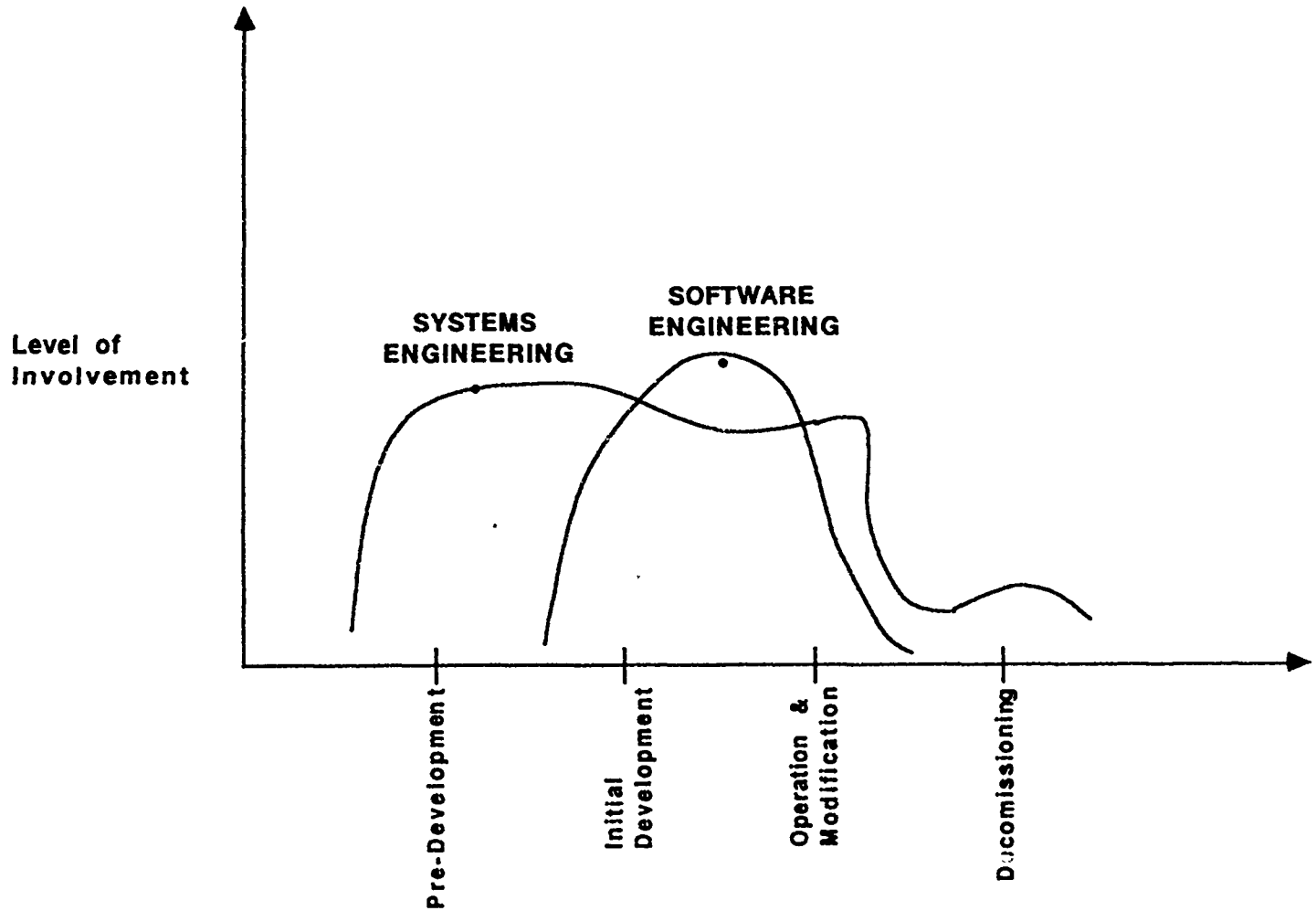


A Systems Engineering Management Structure



(Eisner)

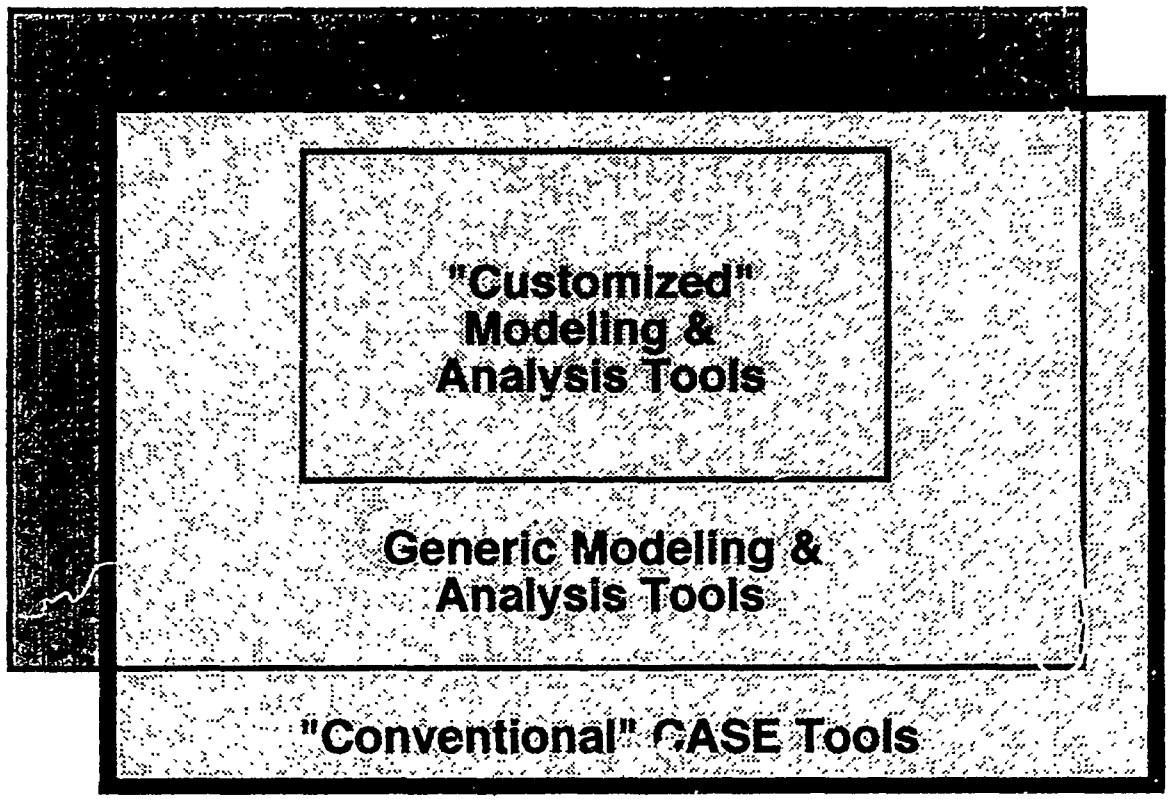
Time Scope


Level of Involvement
SYSTEMS ENGINEERING
SOFTWARE ENGINEERING
Pre-Development
Initial Development
Operation & Modification
Decomissioning

Systems Engineering "Versus" Software Engineering

	Systems Engineering	Software Engineering
Alternative Design Methods	H	M
Multidisciplinary Orientation	H	L
Requirements Analysis & Prototyping	H	M
Criteria-Based Trade-Off Analysis	H	L
Detailed Software Specifications	M	H
Optimal Software Production	M	H
Methods Integration (Re-) Planning	M	L
Education & Training Curricula	M	M
Artifact Profiling	M	M
Applications Range Assessment	M	M
Measures & Standards	M	M
Processes/Metrics Introspection	M	M

Computer-Aided Systems Engineering



Criteria-Based Evaluation & Assessment --> The Tools Matrix

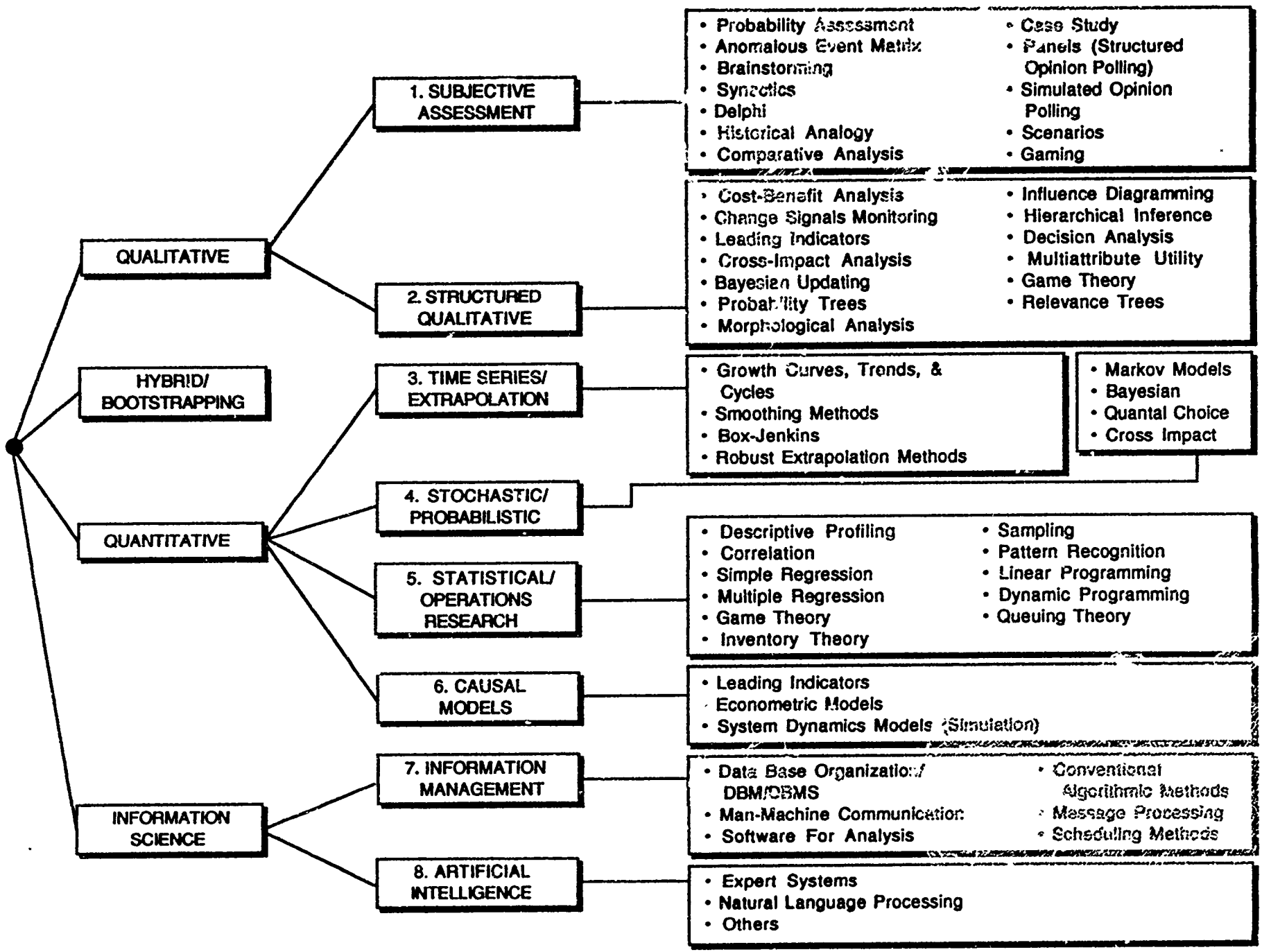
- **Tools Can Be Assessed According to Their:**
  - **"Fit" (with a Systems Engineering Phase, Method, or Objective**
  - **Cost (to Include Acquisition, Training & Use)**
  - **Quality of Output**
  - **Ease of Use**
  - **Robustness**
  - **Support ...**

. OF PACKAGE	PLATFORM	OPERATING SYSTE	LIFE CYCLE PHASE	EXPERIENCE	P
3-D Computerscape	IBM/Clone	DOS	Prototyping/Modeling	Novice	89
3-D Graphics Toolkit	IBM/Clone	DOS	Prototyping/Modeling	Intermediate	80
4th Dimension	Macintosh	Macintosh	System Transfer	Intermediate	895
ABC Flowcharter	IBM/Clone	Windows	Prototyping/Modeling		295
ACD-Action Chart Diagrammer	IBM/Clone	DOS	Requirements Analysis	Intermediate	495
ACPVision	Macintosh	Macintosh	Software Selection/Design	Intermediate	495
Acta Advantage	Macintosh	Macintosh	Requirements Analysis	Novice	129
Action Art	IBM/Clone	DOS	Prototyping/Modeling	Novice	50
Adobe Illustrator 88	Macintosh	Macintosh	Other	Intermediate	495
AEC Information Manager	Macintosh	Macintosh	Project Management	Casual	695
Aegis Showcase F/X	Macintosh	Macintosh	Prototyping/Modeling	Intermediate	395
Agenda	IBM/Clone	DOS	Project Management	Intermediate	395
Aldus Persuasion	Macintosh	Macintosh	Prototyping/Modeling	Intermediate	495
Anatool	Macintosh	Macintosh	Prototyping/Modeling	Intermediate	925
Animation Works	Macintosh	Macintosh	Requirements Analysis	Intermediate	200
AppMaker, The Application Gen	Macintosh	Macintosh	Prototyping/Modeling	Casual	295
ATLAS MapMaker	Macintosh	Macintosh	Requirements Analysis	Casual	495
AuthorWare Professional	Macintosh	Macintosh	Prototyping/Modeling	Expert	8000
Black & White Movies	Macintosh	Macintosh	Other	Novice	50
BLUES	Macintosh	Macintosh	Software Selection/Design	Casual	1875
Brainstormer	IBM/Clone	DOS	Requirements Analysis	Novice	75
Business Graphics II	IBM/Clone	DOS	Prototyping/Modeling		195
Business Graphics Toolkit	Macintosh	Macintosh	Other	Novice	80
CA- Cricket Presents	Macintosh	Macintosh	Requirements Analysis	Casual	495
CA-Cricket Graph	Macintosh	Macintosh	Prototyping/Modeling	Casual	195
CA-Cricket Presents	Macintosh	Macintosh	Other	Casual	199
CA-ESTIMACS	IBM/Clone	DOS	Prototyping/Modeling		0
Canvas	IBM/Clone	DOS	Requirements Analysis	Casual	300
Canvas	Macintosh	Macintosh	Other	Casual	299
CASE: PM	IBM/Clone	OS2	Software Selection/Design	Experienced	995
CASE:W	IBM/Clone	Windows	Prototyping/Modeling	Intermediate	795
Chart Master	IBM/Clone	DOS	Prototyping/Modeling	Intermediate	395
Charts Unlimited	IBM/Clone	DOS	Prototyping/Modeling		35
Choreographer	IBM/Clone	OS2	Prototyping/Modeling	Experience	7500
Cinemation	Macintosh	Macintosh	Prototyping/Modeling	Intermediate	495
Clarion Personal Developer	IBM/Clone	DOS	Prototyping/Modeling		169
CoCoPro	Macintosh	Macintosh	Project Management	Intermediate	495
Collage Display Utilities	IBM/Clone	DOS	Prototyping/Modeling	Novice	90
ColoRIX VGA Paint	IBM/Clone	DOS	Other		199
Company Ladder	IBM/Clone	DOS	Requirements Analysis	Novice	80
Cost Benefits Models	IBM/Clone	DOS	Requirements Analysis		40
Cost/Schedule Workshop (CSW)	Macintosh	Macintosh	Project Management	Casual	595
Course Builder	Macintosh	Macintosh	Prototyping/Modeling	Intermediate	395
CPM / PERT	IBM/Clone	DOS	Project Management	Casual	249
Dan Bricklin's Demo II	IBM/Clone	DOS	Prototyping/Modeling	Casual	195
Datasurf	IBM/Clone	DOS	Requirements Analysis	Novice	120
Decision Analysis	IBM/Clone	DOS	Requirements Analysis	Novice	45
Decision Analysis By TreeAge	Macintosh	Macintosh	Requirements Analysis	Intermediate	495
Decision Analysis Techniques	Macintosh	Macintosh	Requirements Analysis	Casual	145

COTS/CASE Tools Sampler

- **Tools Not Usually Associated with *Software* Engineering + Some of Those That Are!!!**
- **Tools That Support Methods & Objectives of the Systems Engineering Life Cycle Phases**
- **Tools That Support:**
  - **Modeling, Charting & Diagramming**
  - **Analysis (eg, Cost-Benefit, Estimation)**
  - **Documentation & "Auditing"**
  - **Management**
  - **Technology Assessment**
  - **Testing & Evaluation ...**

A Taxonomy Of Analytical Methods & Sub-Methods



Life Cycle Phase-by-Phase Organization & Categorization

- **Pre-Phases**
  - **Project Management Tools**
  - **Simple Graphics Tools**
  - **Modeling & Analysis Tools**
  - **"*Visualization*" As A Way of Life**
- **Early Phases & Activities**
  - **Requirements, Requirements, Requirements**
  - **Requirements Models, Tools & "Environments"**
  - **Trade-Off Analyses**
  - **Constraint Analysis ...**

Life Cycle Phase-by-Phase Organization & Categorization (Continued)

- **Mid-Phases & Activities**
  - **Specification (from Multiple Perspectives)**
  - **On-Going Requirements Traceability**
  - **Design (from Multiple Perspectives)**
  - **Development (Often Evolutionary)**
- **Later Phases & Activity**
  - **T&E; V&V**
  - **On-Going Requirements Traceability**
  - **Documentation (Throughout)**
  - **Configuration Management**

Exemplar CAS(ystems)E Tools

- **Requirements Modeling**
  - **QFD Capture**
  - **RDD**
  - **DOOR**
  - **TopDown**
  - **DATA**
  - **IDEF0**
  - **Inspiration**
  - **Systems Engineering Design Software (SEDSO)**
  - **Conventional CASE Tools**
  - **Many CAD/CAM/CALS Tools**
  - **Some Evaluation & Trade-Off Analysis Tools**

Exemplar CAS(ystems)E Tools

- **Simulation & Prototyping**
  - **Extend**
  - **iThink**
  - **MicroSaint**
  - **MetaDesign**
  - **Skylights**
  - **ToolBook**
  - **Show Partner**
  - **TAE+**
  - **Access**
  - **LabView**
  - **Design/IDEF/IDEF0**
  - **Visual Basic**
  - **Prograph**

Exemplar CAS(ystems)E Tools

- **Evaluation & Trade-Off Analysis**
  - **Logical Decision**
  - **Expert Choice**
  - **DecisionMap**
  - **Decision Analyst**
  - **Lightyear**
  - **ADAM 2**
  - **Arborist**
  - **COMPARE!**
  - **Best Choice 3**
  - **Criterium**
  - **Crystal Ball**
  - **David**
  - **Decision Pad**
  - **Equity**

Exemplar CAS(ystems)E Tools

- **Expression Tree**
- **HIVIEW**
- **SuperTree**

Exemplar CAS(ystems)E Tools

- **Testing & Reliability**
  - RPP
  - PC Availability
  - PC Predictor
  - Tiger Computer Program(s)
  - Machanical Reliability Prediction Program (MRP)
  - Maintainability Effectiveness Analysis Program (MEAP)
  - Optimum Repair Level Analysis (ORLA) Model
  - Equipment Designer's Cost Analysis System (EDCAS)
  - Network Repair Level Analysis (NRLA)
  - OPUS Model
  - VMETRIC

Exemplar CAS(ystems)E Tools

- Systems & Logistics Integration Capability (SLIC)
- Life Cycle Cost Calculator (LCCC)
- Cost Analysis Strategy Assessment (CASE)
- Life-Cycle Model for Defense Material Systems

Exemplar CAS(ystems)E Tools

- **Technology Forecasting**
  - **4CAST/2**
  - **Autocast**
  - **Forecast!**
  - **GLIM**
  - **MTS**
  - **NCSS**
  - **SAS**
  - **SIBYL/Runner**
  - **STORM**

Exemplar CAS(ystems)E Tools

- **Risk Analysis**
  - **@Risk**
  - **RiskWatch**
  - **Automated Risk Evaluation System (ARES)**
  - **Bayesian Decision Support System (BDSS)**
  - **The Buddy System**
  - **Continuous Risk**
  - **Los Alamos Vulnerability & Risk Assessment (LAVA)**

Exemplar CAS(ystems)E Tools

- **Prototyping Tools for Software Systems Engineering**
- **Tool "Requirements"**
- **Exemplar Tool Types**
- **Specific Tools ...**

Impact

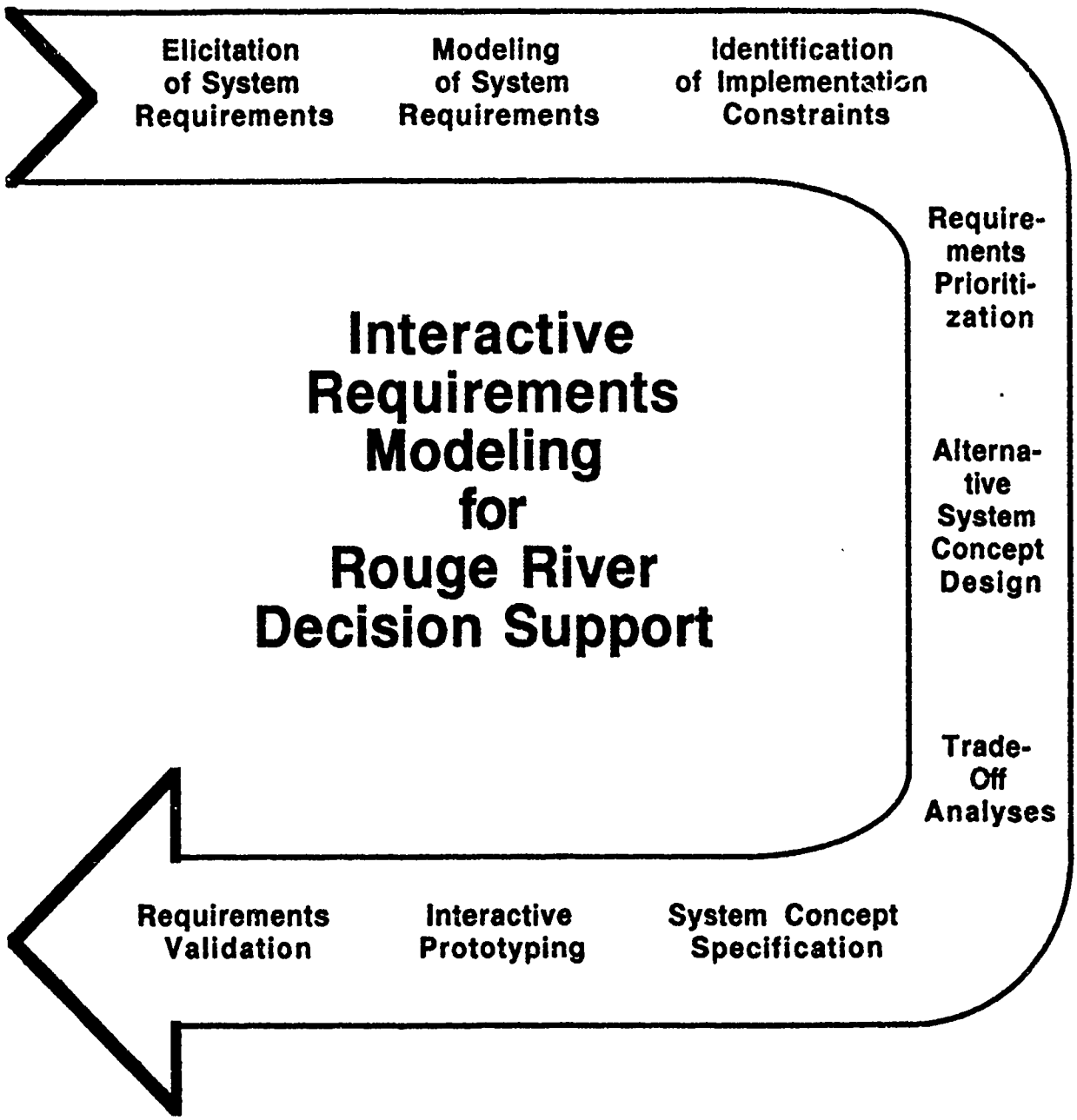
- Software Support For All Phases of Life Cycle
- Capability to Store & Model Requirements
  Data ---> Prototypes ---> Specifications
  Designs
- "Audit Trail" of Design/Development Process
- Capability to Store Designs, Models, Prototypes & Modules & Reuse the Concepts, Data, Models & Software

(44)

Interactive Requirements Modeling & Prioritization & System Concept Design

for

Rouge River Decision Support


Elicitation of System Requirements
Modeling of System Requirements
Identification of Implementation Constraints
Requirements Prioritization
Alternative System Concept Design
Trade-Off Analyses
Requirements Validation
Interactive Prototyping
System Concept Specification
Interactive Requirements Modeling for Rouge River Decision Support

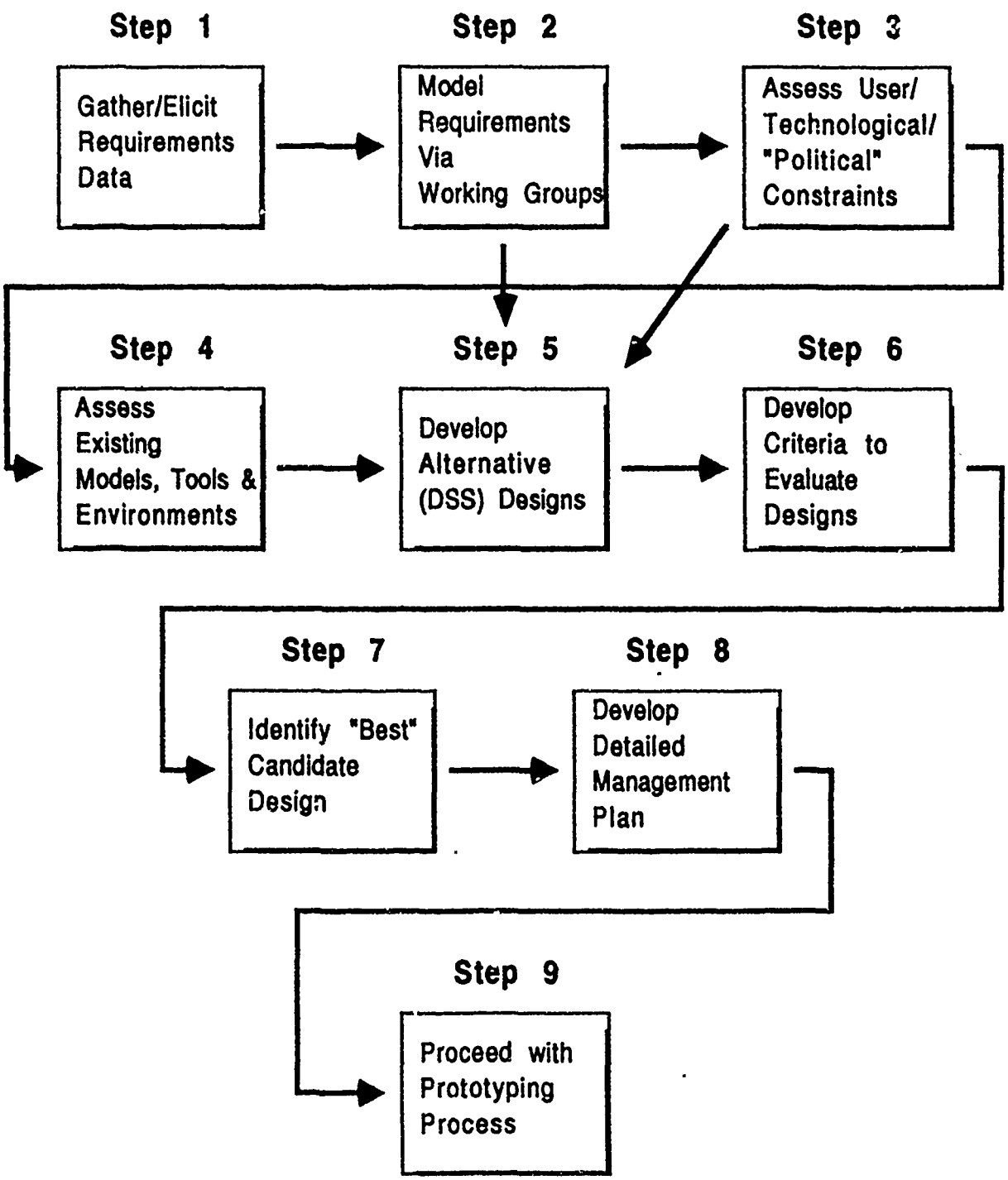
The Process

- Collect Requirements Data Via Individual & Group Discussions & Via Codified Requirements Data
- Document Requirements Data -- Not in Elaborate "Specs" -- But in a Form that Lends Itself to Analysis & Modification
- Organize the Requirements Data in Alternative Forms for Iteration -- Such as in Simple Outline Form & in a Hierarchical Form
- Assess, Rank-Order, Trade-Off -- "Reconcile" Requirements
- Identify Off-the-Shelf & Existing Special Purpose Applications Programs & Implementation Environments
- Match the Requirements to the Existing Systems
- Develop a System Requirements Specification that Lies at the Intersection of Requirements, Existing Systems & Constraints

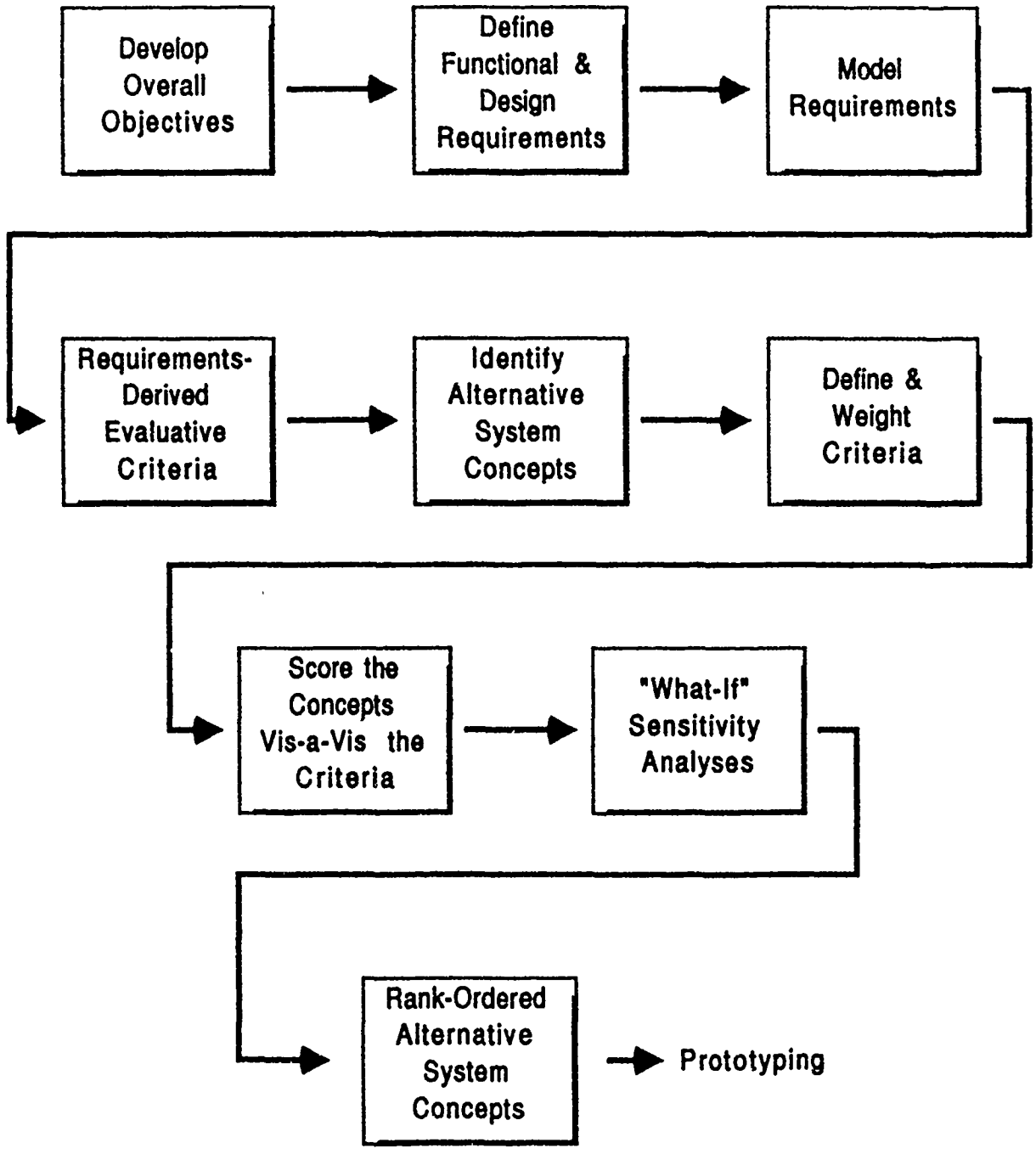
Some Special Assumptions & Features of the Process

- The Process Assumes the Value of "Participatory Design"
- The Process Assumes the Value of Iterative Design & Prototyping -- to a Point!
- The Process Assumes the Value of a Life Cycle-Driven System Development Methodology
- The Process Assumes the Need to Make Requirements Explicit & to "Model" Requirements to Determine What are the "Most," "Moderately," and "Not Quite as" Important Requirements
- The Process Assumes the Stupidity of Re-Inventing the Wheel
- Requirements will Be Captured, Modeled & Communicated to All "Stakeholders" During the Process

Requirements Modeling --> Prototyping Process --> Management Plan



System Concept Evaluation Process



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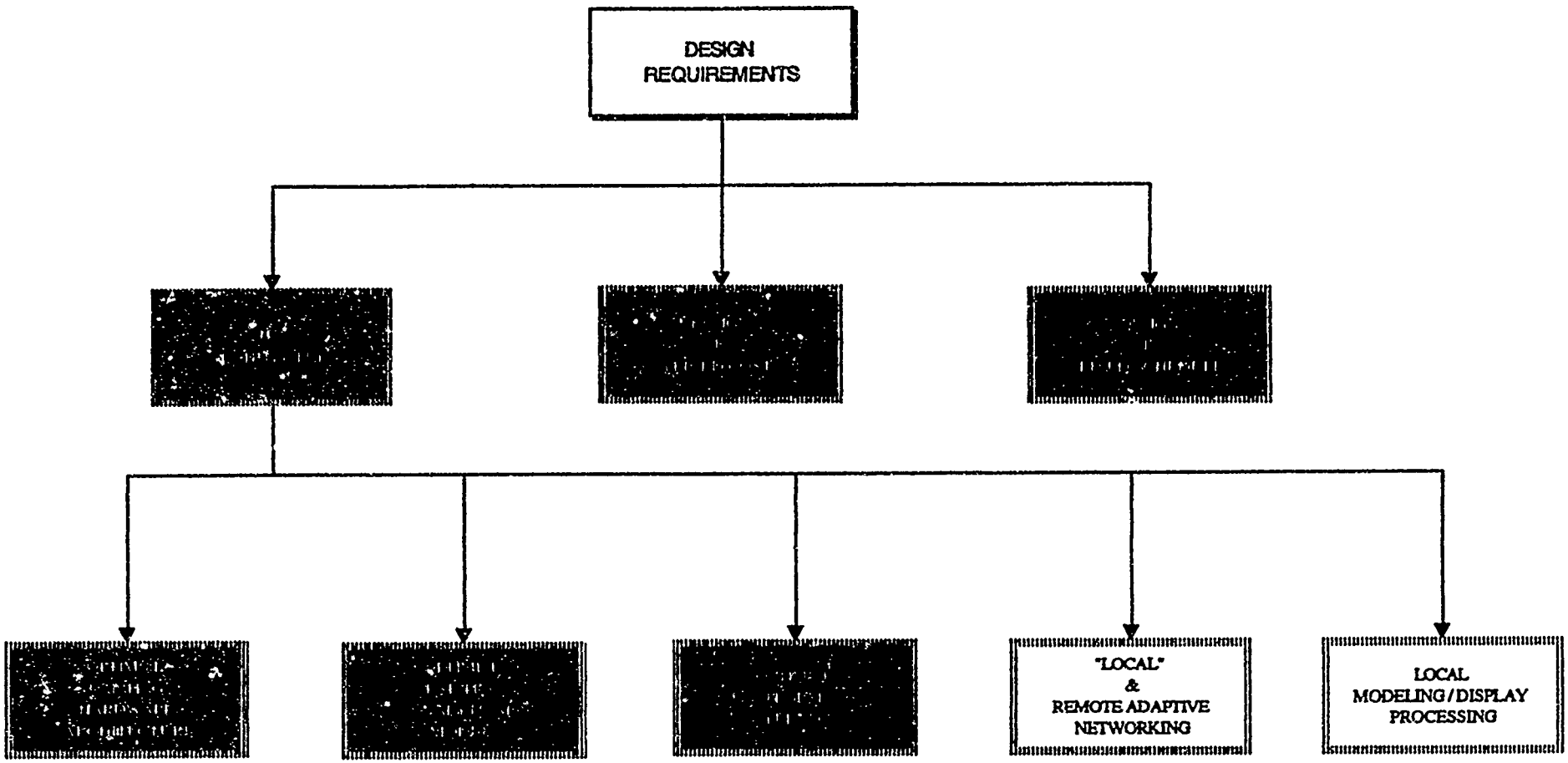
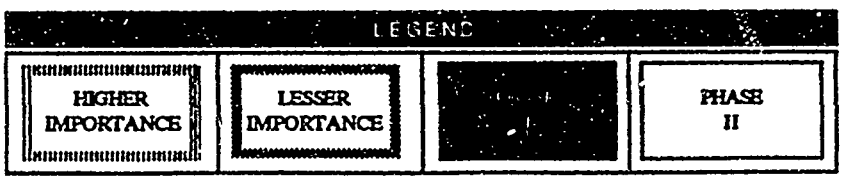
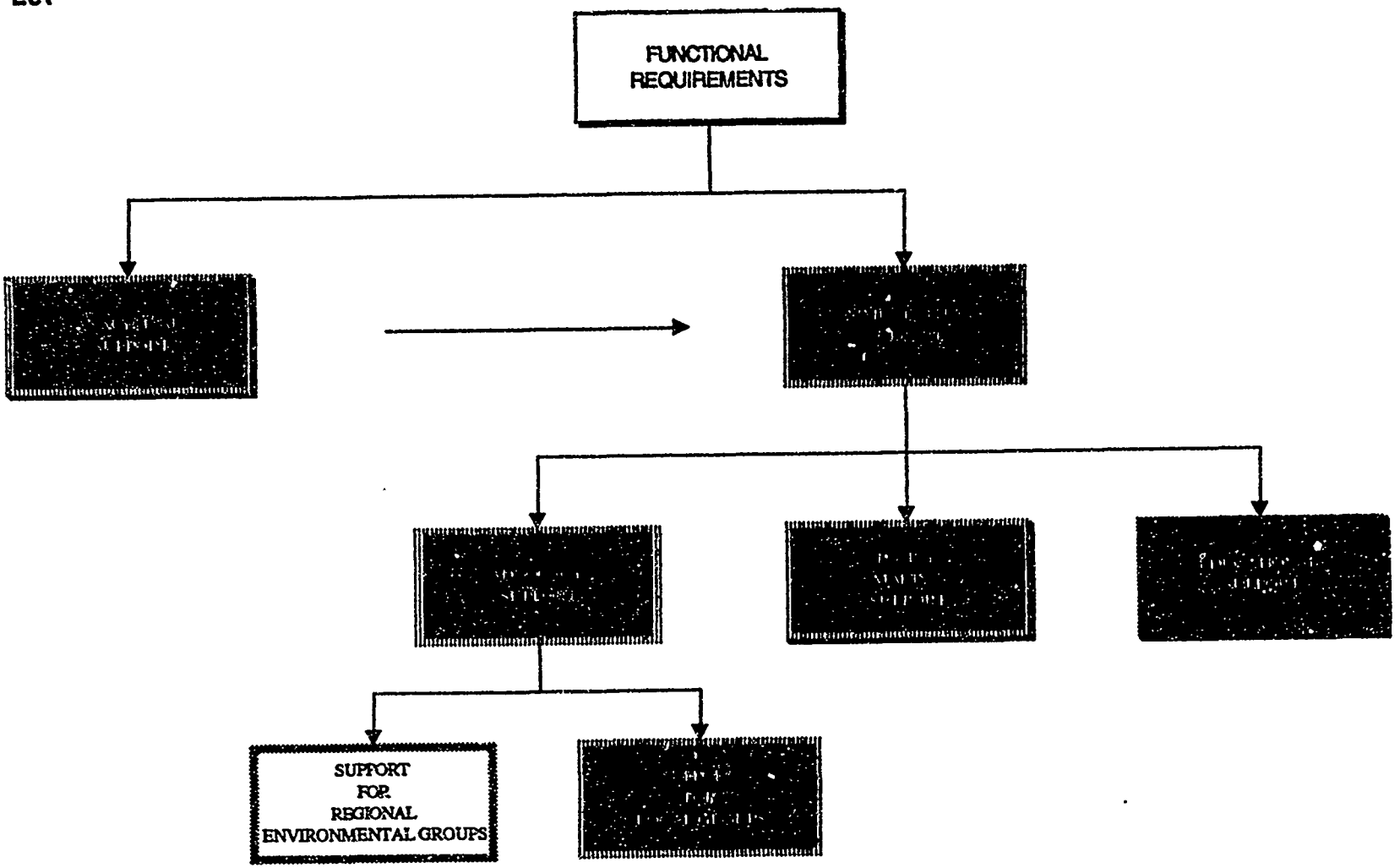

DESIGN
REQUIREMENTS
"LOCAL"
&
REMOTE ADAPTIVE
NETWORKING
LOCAL
MODELING/DISPLAY
PROCESSING


LEGEND
HIGHER
IMPORTANCE
LESSER
IMPORTANCE
PHASE
II

Top Lev


FUNCTIONAL REQUIREMENTS
SUPPORT FOR REGIONAL ENVIRONMENTAL GROUPS
LEGEND
HIGHER IMPORTANCE
LESSER IMPORTANCE
PHASE II

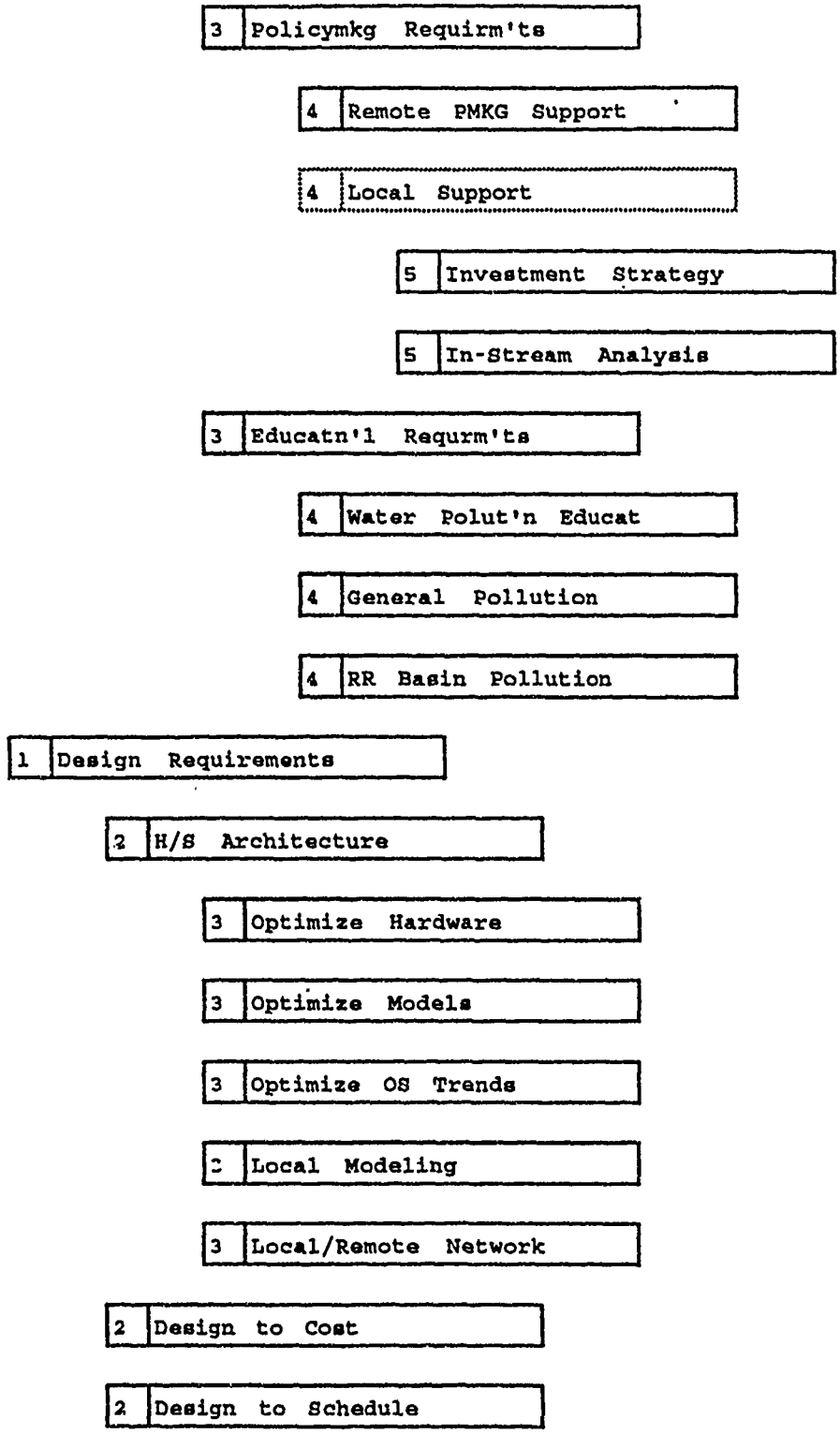
Decision Outline on DSS H/S Architecture

Alternatives:

- System Concept #1
- System Concept #2
- System Concept #3

Factors:

- R | DSS H/S Architecture
  - 1 | Funct'l Requirements
    - 2 | Analyt'l Requiremt's
      - 3 | Flow Analysis
        - 4 | Whole River Simulate
        - 4 | Threshhold Analysis
        - 4 | Quasi-RT Analysis
        - 4 | Realtime Analysis
      - 3 | Map Partitioning
        - 4 | Scenario-Driven
        - 4 | Clutter/De-clutter
      - 3 | Querying
        - 4 | Cost-Result Analyses
        - 4 | Comparative Analyses
        - 4 | Sensitivity Analyses
    - 2 | Comunicatn's Reqm'ts
      - 3 | Advocacy Requirem'ts
        - 4 | Regn'l Group Support
        - 4 | Local Support


3 Policymkg Requirm'ts
4 Remote PMKG Support
4 Local Support
5 Investment Strategy
5 In-Stream Analysis
3 Educatn'l Requrm'ts
4 Water Polut'n Educat
4 General Pollution
4 RR Basin Pollution
1 Design Requirements
2 H/S Architecture
3 Optimize Hardware
3 Optimize Models
3 Optimize OS Trends
3 Local Modeling
3 Local/Remote Network
2 Design to Cost
2 Design to Schedule

Decision Results on DSS H/S Architecture

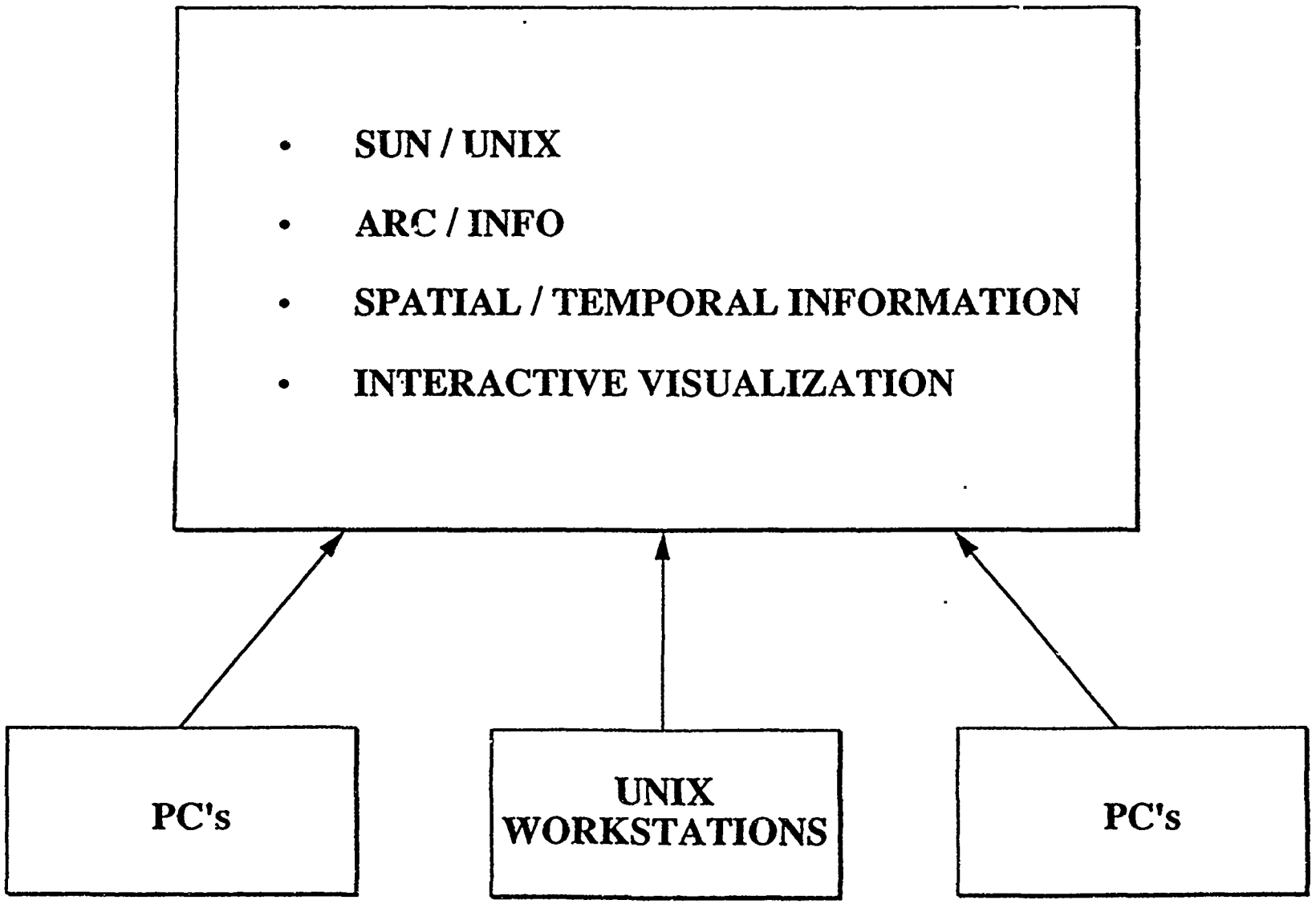
Alternative	Score	Comments
System Concept #3	98.55	Concept for PC/NT-based DSS with full networking
System Concept #2	75.84	Concept for UNIX-based system w modest networking
System Concept #1	57.84	Concept that calls for UNIX workstation-based DSS

Comments: "Optimal" hardware/software architecture

SYSTEM CONCEPT I

- SUN / UNIX
- ARC / INFO
- SPATIAL / TEMPORAL INFORMATION
- INTERACTIVE VISUALIZATION

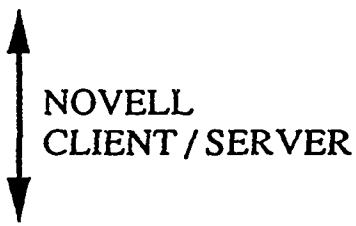
SYSTEM CONCEPT II



SYSTEM CONCEPT III

MODELING

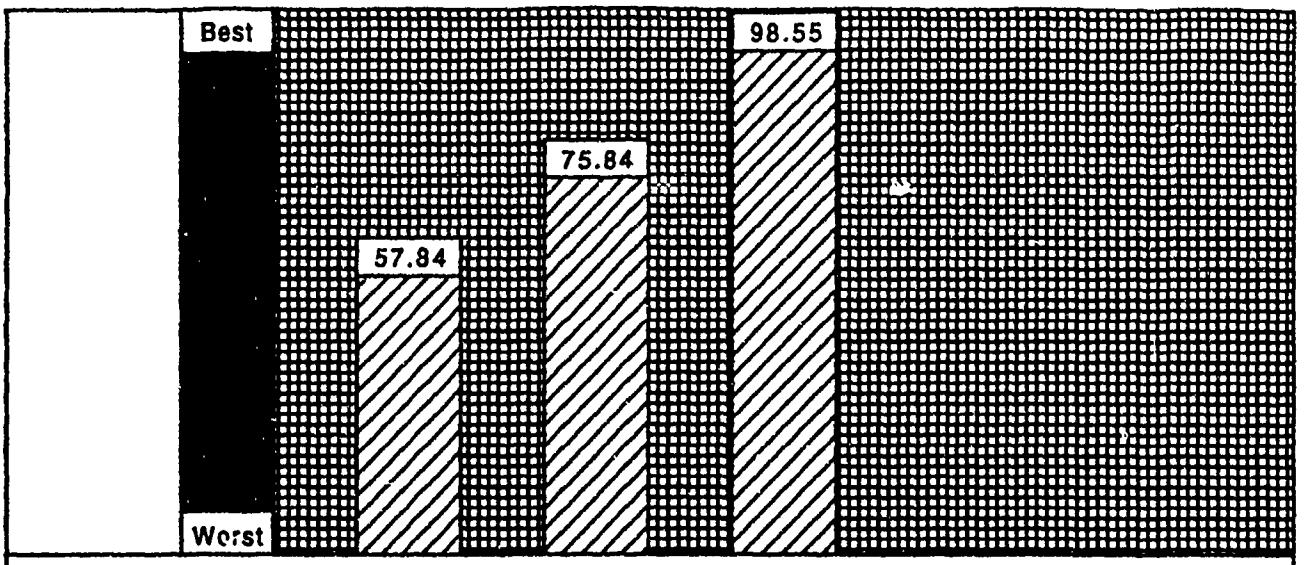
- **PC**
- **WINDOWS NT**
- **GUT FOR PRE / POST PROCESSING (& ANIMATION)**



- **SUN / UNIX**
- **ARC / INFO**
- **ORACLE**
- **SPATIAL / TEMPORAL INFORMATION**

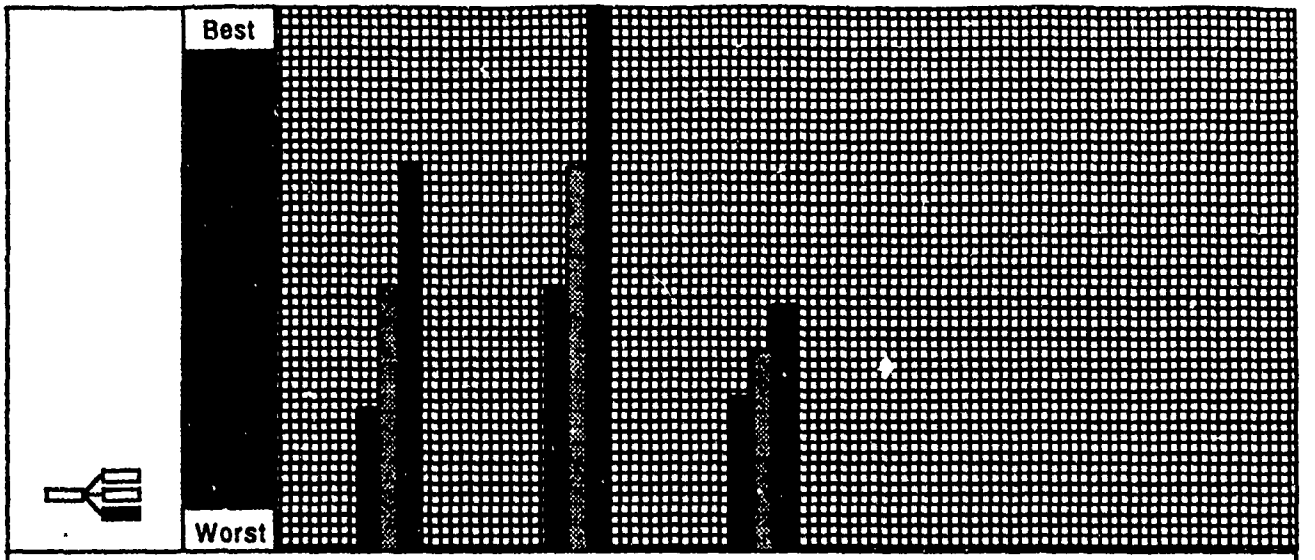
SERVER

Decision Results on DSS H/S Architecture



COMMENTS: "Optimal" hardware/software architecture

Decision Comparison on Comunicatn's Reqm'ts

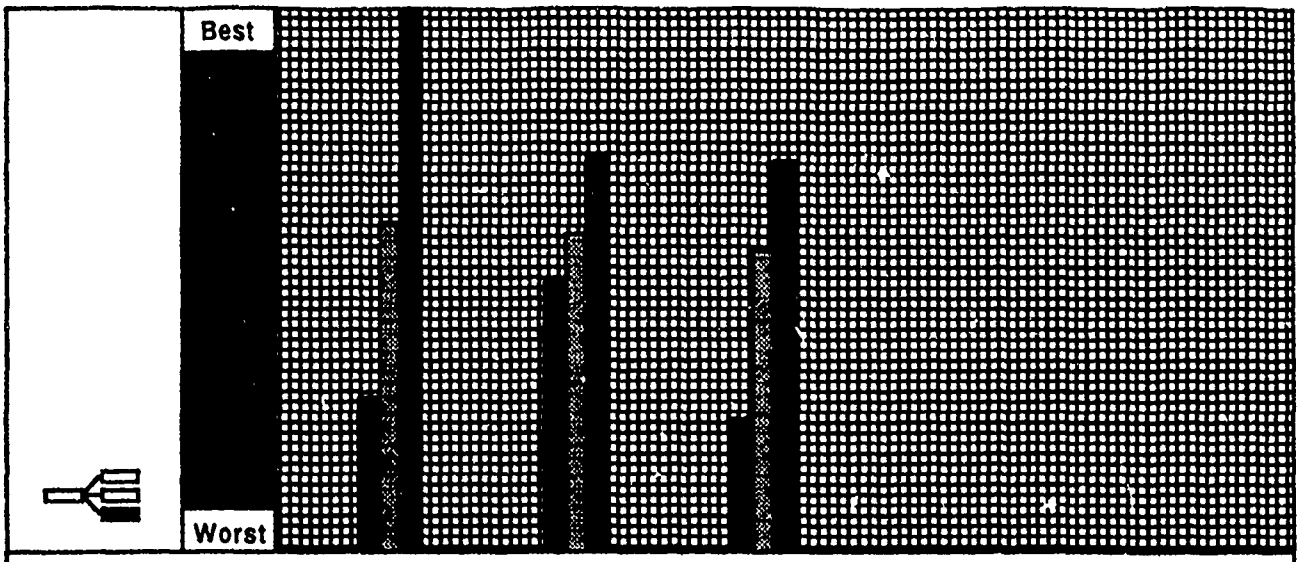


Advocacy Requirem'ts
Policymkg Requirm'ts
Educatn'l Requrm'ts

COMMENTS: Requirements that describe communicat'ns functions

System Concept #1 System Concept #2 System Concept #3

Decision Comparison on Design Requirements

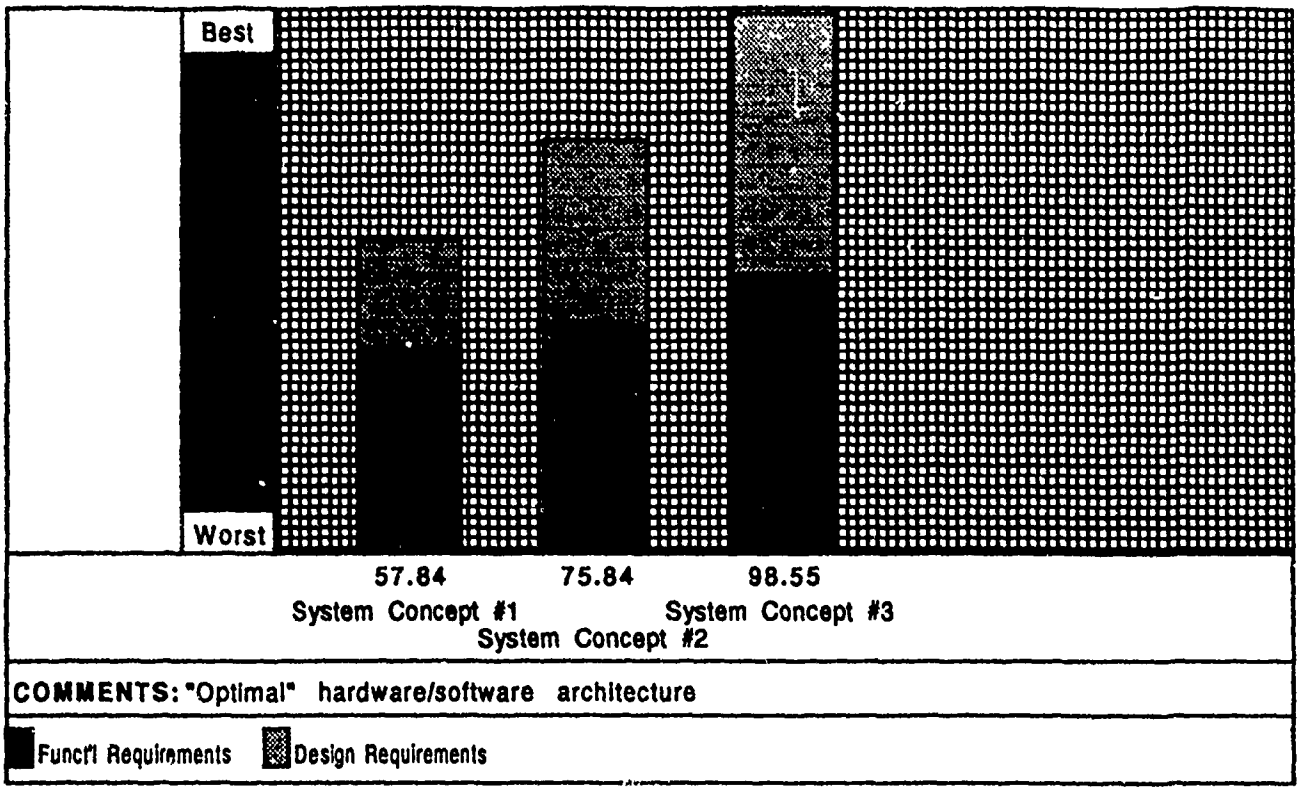


H/S Architecture
Design to Schedule
Design to Cost

COMMENTS: Requirements that refer to design considerations

System Concept #1 System Concept #2 System Concept #3

Decision Comparison on DSS H/S Architecture



COMMENTS: "Optimal" hardware/software architecture

Funcl'l Requirements Design Requirements

Trends

- **Toward I-CASE**
- **Toward Greater Distribution**
- **Toward Automation ...**

Key References

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